

On ‘The spectral and temporal properties of an Ultra–Luminous X–ray source in NGC 6946’, by Seniorita Devi et al.

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Abstract

A recent paper (arXiv:0804.3463) claims that the presence of a soft X–ray component in an X–ray source in NGC 6946 provides strong evidence that its black hole mass is definitely $> 100M_{\odot}$, and more probably $\sim 400M_{\odot}$, even if the source is beamed.

I show that the data are instead very compatible with a black hole mass of only $5M_{\odot}$, radiating isotropically (i.e. no beaming) and a mass transfer rate about 60 times the Eddington value, i.e. $1.25 \times 10^{-5}M_{\odot} \text{ yr}^{-1}$. Such a system is very similar to the probable descendant of the Galactic X–ray binary Cygnus X–1 once the supergiant companion evolves to fill its Roche lobe.

Discussion

The X–ray source NGC 6946 X–7 has an inferred blackbody luminosity $L_{\text{bb}} \simeq 2.8 - 3.7 \times 10^{39} \text{ erg s}^{-1}$ and an inferred blackbody radius $R_{\text{sph}} \simeq 6 \times 10^8 \text{ cm}$. Seniorita Devi et al. (2008: hereafter SD08) derive a black hole mass $M = 100 - 400M_{\odot}$ by assuming that $R_{\text{sph}} = 10GM/c^2$, corresponding to the inner edge of an accretion disc.

However this is not the only possibility. According to Shakura & Sunyaev (1973) an accreting source fed mass at a rate \dot{M} greater than the Eddington value \dot{M}_{E} emits a bolometric luminosity

$$L_{\text{bol}} \simeq L_{\text{E}} \left[1 + \ln \left(\frac{\dot{M}}{\dot{M}_{\text{E}}} \right) \right].$$

Further, the characteristic lengthscale for the blackbody disc emission is now not a few Schwarzschild radii (as assumed in SD08) but instead

$$R = \frac{27}{4} \frac{\dot{M}}{\dot{M}_{\text{E}}}$$

(cf Begelman et al., 2006). In addition, Shakura & Sunyaev (1973) show that the source expels most of the super–Eddington accretion in an outflow with toroidal geometry, making geometrical collimation by some factor $b < 1$ likely (cf King et al., 2001). Thus the high apparent luminosity of ULXs results from two effects: (a) a bolometric luminosity raised above L_{E} by the natural logarithm of the Eddington ratio, and (b) geometrical collimation, i.e.

$$L_{\text{app}} \simeq \frac{L_{\text{E}}}{b} \left[1 + \ln \left(\frac{\dot{M}}{\dot{M}_{\text{E}}} \right) \right].$$

In a recent paper (King, 2008) I showed how one could decide which of these was the more important effect in those ULXs where a soft blackbody component is detected, as in NGC 6946 X-7. Consistency between the observed luminosity L and the inferred blackbody radius (also affected by beaming as $R_{\text{sph}} = b^{1/2}R$) leads to the relation

$$b = \frac{0.016m_1}{L_{40}} \left[1 + \ln \left(\frac{490R_9}{m_1} b^{1/2} \right) \right]$$

For an assumed accretor mass $M_1 = m_1 M_\odot$, inferred luminosity $10^{40} L_{40} \text{erg s}^{-1}$, and black body radius $10^9 R_9 \text{cm}$, this equation can be solved to find the beaming factor b required to produce the observed apparent luminosity.

In King (2008) I showed that it is generally the Eddington logarithm which dominates the ULX effect, and beaming is rather mild. With typical ULX values $m_1 = 10$, $L_{40} = R_9 = 1$ one finds beaming factors $b \sim 0.76$ and Eddington ratios ~ 40 , corresponding to mass transfer rates $\dot{M} = 1.0 \times 10^{-5} M_\odot \text{yr}^{-1}$ (for matter of normal composition). These parameters are exactly as expected for the thermal-timescale mass transfer expected when the supergiant companion in a high-mass X-ray binary fills its Roche lobe after the standard wind-fed phase. This shows that one naturally gets a population of stellar-mass ULXs associated with star formation, as observed for example in the Cartwheel galaxy (cf King 2002).

For the specific case of NGC 6946 X-7 we have $L_{40} \sim 0.28 - 0.37$ and $R_9 \sim 0.6$. The equation for b only has solutions with $b < 1$ provided that the black hole mass is low ($m_1 < 5$). With $L_{40} = 0.37$ we find $M_1 = 5M_\odot$, $b = 1$, $\dot{M} = 1.25 \times 10^{-5} M_\odot \text{yr}^{-1} = 60\dot{M}_E$.

I conclude that the observations of NGC 6946 X-7 can be explained by a stellar-mass ($5M_\odot$) black hole receiving thermal-timescale mass transfer in a high-mass X-ray binary. No beaming is required, nor indeed is a very high black hole mass.

References

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